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An Improved Quantum Ant Colony Algorithm and its Application*

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Abstract

The algorithm in this paper is based on the combination of Quantum Evolutionary algorithm (QEA) and Ant Colony System (ACS), a new algorithm, Quantum Ant Colony Algorithm (QACA) is proposed in this paper. The core is that Q-bit and quantum rotation gate adopted in QEA are introduced into ACS to represent and update the pheromone respectively, so it has better diversity and global search capacity. The experimental result demonstrates that QACA can get better solutions to some Traveling Salesman Problems (TSP) than the solutions given in TSPLIB.

Key words: Quantum Algorithm; Quantum Evolutionary; Ant Colony System; Quantum Ant Colony Algorithm; TSP

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1. Introduction

The intelligent algorithm has been paid more and more attention, such as neural network, genetic algorithm, ant colony algorithm, particle swarm algorithm, which they are used to solve combinatorial optimization and NP- problem, but these algorithms have their own advantages and defects. Nowadays, all kinds of optimization algorithm together, produce respective advantage, construct a better algorithm, it has become a hotspot.

Quantum evolutionary algorithm [1] is KuK-Hyuan Han proposed in 2002, the algorithm is based on the theory of quantum evolutionary algorithm. It absorbed the quantum computation [2] in the superposition state, coherence and entanglement of the quantum algorithm it break traditional algorithm limit, showing a better performance. The algorithm has become a hot topic for its unique computational performance, it has been applied in a variety of optimization problems, especially to solve the classic calculation of NP hard problems.

Ant colony algorithm is affected by the nature of the ant searching food behavior, it is proposed by M. Dorigo in 1992 firstly.

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Individual ants are fragile, but the whole ant colony can complete the work that the individual is unable to undertake, with the help of the ant pheromone chemical communication and information transfer, and demonstrated a positive feedback phenomenon. It is performed by the ants in a path, the ants is more, the path is selected probability is higher. The positive feedback mechanism and communication mechanism of ant colony algorithm is the two important foundations. The algorithm has strong robustness and capabilities in searching better solution, but at the same time also has some flaws, such as slow convergence speed, easy stagnation behavior. Aiming at the deficiency of the algorithm, some scholars put forward the improved ant colony algorithm. Such as St u tzle & Hoos raised the max-min ant colony algorithm in 1996, Dorigo proposed ant colony system in 1997, Maniezzo proposed approximate nondeterministic tree search in 1999 [3], Cord and others proposed the optimal worst ant colony algorithm in 2002 [4], Blum proposed a hypercube ant colony algorithm in 2004 [5]. The ant colony algorithm in combinatorial optimization, computer network routing, continuous function optimization, robot path planning, data mining, network optimization and other fields have achieved outstanding results.

The algorithm is based on ant colony algorithms, state vector and quantum rotation gate of quantum evolutionary algorithm is introduced in ant colony algorithm, put forward a kind of new algorithm -quantum ant colony algorithm. In this algorithm the state vector and quantum rotation gate respectively representing and updating pheromone, accelerate the algorithm convergence speed and avoid premature convergence. By solving the TSP example results show that the algorithm can achieve better than other heuristic intelligent optimization algorithm the results.

2. TSP Problem

Traveling salesman problem is a classical combinatorial optimization problem, which belongs to the NP-hard problems. It can be described as follows: Give a graph G = (V, E), E is the set of edges, nonnegative weights are w (E) on each side, how to find the Hamilton ring of G, making w (E) is minimum? Its practical meaning is: for a given K City, traveling salesman from a city of departure access the rest of the city not repeated returned the starting city finally, the requirements of all traveling salesmen to find a shortest route to travel. With the growing of the number of city, the solution space will grow exponentially, through the exhaustive method cannot solve, therefore optimization algorithm is used to solve the TSP is very necessary. Such as simulated annealing algorithm, ant colony algorithm, genetic algorithm, particle swarm algorithm. The algorithms have respective advantages and defects, some fast operation but needs computer storage capacity, some need a computer memory but a small amount of computation time is too long, some fast operation but solving city small scale. In order to solve the above problems, this paper puts forward a new quantum ant colony algorithm to solve TSP [6].

3. Quantum Ant Colony Algorithm

3.1 Quantum coding characteristic

Quantum bit is the basic unit of information of quantum computing, is defined a unit vector of two-dimensional complex vector space , the space is made of a pair of orthonormal basis {| 0>, | 1>} . A qubit can represent 0 or 1, and can be between 0 and 1 states of arbitrary superposition state. That is, a qubit can be in | 0> or | 1>, or in an intermediate state between the two, so the state of a qubit can be expressed as: $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$ where α and β are a pair of real numbers, express the probability amplitude of | 0> and | 1 > ,"|>" express a quantum state, $|\alpha|^2$ and $|\beta|^2$ express the probability of a quantum bit "0" state and "1" state, and $|\alpha|^2 + |\beta|^2$ =1, that is, a quantum Bits contains the information of 0 and 1, then the length of m of a quantum bit can express 2^m different states. Definition ξ ($\xi \in$(- π , π]) is the phase of a quantum bit, $\xi = \arctan(\beta/\alpha)$, the i (i =1 , 2 , …, m) phase of quantum bits is $\xi_i = \arctan(\beta_i/\alpha_i)$. the symbol d_i denotes the product of the probability of i quantum bit α_i and β_i, $d_i = \beta_i/\alpha_i$, which d_i represents the phase ξ_i of the quantum-bit plane coordinates in the location shown in Figure 1, it can greatly reduce the space and time to searcthe optimal solution. so there is m quantum bit of j 's probability amplitude can be expressed as:

$$p_j = \begin{pmatrix} \alpha_1 | \alpha_2 | \ldots | \alpha_m \\ \beta_1 | \beta_2 | \ldots | \beta_m \end{pmatrix} \tag{1}$$

Where $|\alpha_i|^2 + |\beta_i|^2 = 1$, i = 1,2, …, m. In the new algorithm, quantum bits represent the pheromone, population size is set n, the pheromone is represented as P =(p_1, p_2,…, p_n), where p_j (j =1,2, …, n)...,) , as equation (1).

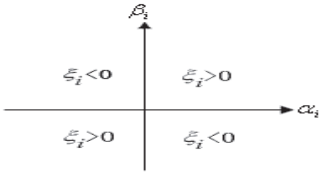

Figure 1 the phase ξ_i of the quantum-bit plane coordinates

3.2 The adaptive strategy of Quantum revolving door

In the quantum algorithm, quantum rotation gate used to update operation. The quantum rotation gate operation is as follows:

$$\begin{pmatrix} \alpha_i' \\ \beta_i' \end{pmatrix} = \begin{pmatrix} \cos(\theta_i) & -\sin(\theta_i) \\ \sin(\theta_i) & \cos(\theta_i) \end{pmatrix} \begin{pmatrix} \alpha_i \\ \beta_i \end{pmatrix} \tag{2}$$

Where i =1,2,…, m , [α_i , β_i]^T for the probability amplitude of the i quantum bit , θ_i for the rotation angle of the i quantum bit, the size and direction according to a predetermined adjustment strategy to get. In the paper, the size and orientation automatically adjusted by a formula. Formula is as follows:

$$\theta_i = \Delta\theta * f(\alpha_i, \beta_i) \tag{3}$$

Where $\Delta\theta$ =20 * exp(- t / t^{max}), it is a variable related with the number of iterations, the role of $\Delta\theta$ is to control the size of the rotation angle of θ_i. Where t is the iteration number, t^{max} is a constant, it is the maximum number of iterations. f (α_i , β_i) is a function of α_i and β_i , its role is to adjust the angle of rotation of θ_i. Expressed as follows:

$$f(\alpha_i, \beta_i) = \left(d_{ibest} / d_{inow} \right) (\xi_{ibest} - \xi_{inow})$$

Where $d_{ibest} = \beta_{ibest} / \alpha_{ibest}$, for the optimal solution of the i quantum bit, α_{ibest} and β_{ibest} for the optimal solution to the probability amplitude of the i quantum bit. $d_{inow} = \beta_{inow} / \alpha_{inow}$ for the current solution of the i quantum bit, α_{inow} and β_{inow} for the probability of the current solution of the i quantum bit. $\xi_{ibest} = \arctan(\beta_{ibest} / \alpha_{ibest})$, $\xi_{inow} = \arctan(\beta_{inow} / \alpha_{inow})$, ξ_{ibest} for the best phase of the i quantum bit, ξ_{inow} for the current phase of the i quantum bit. Definition: f (α_i , β_i) > 0, θ_i , the counter-clockwise rotation, when f (α_i , β_i) <0, θ_i, the clockwise rotation. Quantum rotation gate updating process can be described as:

$$p_j^{t+1} = G(t) * p_j^t \tag{4}$$

Where the superscript t is the number of iterations, G(t)for the quantum rotation gate of t iteration, p_j^t for the probability amplitude of the t iteration, p_j^{t+1} for the probability amplitude of the t+1 iteration, p_j^t and p_j^{t+1} representation such as equation (1).

2.3 Process description of quantum ant colony algorithm

Here to QACA solve City Litter Transportation Problem, QACA algorithm steps:

①Initialization: the population of n individuals $P(t)$ = ($p_1^t, p_2^t \ldots p_n^t$) , where p_j^t (j =1,2, …, n)for the j individual of the t and its description such as:

$$p_j^t = \begin{pmatrix} \alpha_1^t \Big| \alpha_2^t \Big| \ldots \Big| \alpha_m^t \\ \beta_1^t \Big| \beta_2^t \Big| \ldots \Big| \beta_m^t \end{pmatrix}$$

Where m is the number of quantum bits, in the beginning, all α_i , β_i (i = 1 ,2 , …, m) are $1/\sqrt{2}$. The initial number of iterations t = 0;

② According to the probability amplitude values in the case $P(t)$ construct R (t), R(t) ={r_1^t, r_2^t , …, r_n^t }, in which r_j^t (j = 1 ,2 , …, n) is a binary string of length m , in which each element is determined by the $|\alpha_i^t|^2$ and $|\beta_i^t|^2$ (i =1,2,…, m) in p_j^t (j=1,2, …, n). Set a random number w(w∈ [0,1]), if $|\alpha_i^t|^2$ > w, then r_i^t =0, or r_i^t =1 (i =1, 2, … m);

③ The total number of litter points is k. n ants will be placed in one of the k points randomly;

④ Ants through repeated application of state transition rules, according to Equation (6) to established a path, and in the process of establishing the path of each step, using the method of the literature [7] mentioned to release pheromones. Its description in equation (5). Until all ants have completed the construction of the solution path;

$$\beta_i(a,b) = \begin{cases} \dfrac{d_{(a,b)} - E_a}{L_a} * 0.5 + 0.5 & (a \neq b) \wedge (L_a \neq 0) \\ 0 & a = b \\ 0.5 & (a \neq b) \wedge (L_a = 0) \end{cases}$$

$$\alpha_i(a,b) = \sqrt{1 - (\beta_i(a,b))^2} \tag{5}$$

$$E_a = \frac{1}{k}\sum_{j=1}^{k} d_{aj}$$

$$L_a = \max\left\{ \left| d_{(a,j)} - E_a \right|, j = 1,2,\ldots,k \right\}$$

$d_{(a,b)}$ expresses the distance between point a and b. The state transition rules in QACA are:

$$b = \begin{cases} \arg\max_{s \in U} \{ [\tau(a,s)].[\eta(a,s)]^\gamma \} & q \leq q_0 \\ b' \quad otherwise \end{cases} \tag{6}$$

- τ (a,b) is the pheromone concentration of the edge (a ,b).
- η $(a,b) = 1/d_{(a,b)}$, representatives the inspired volume of the edge (a ,b).

● γ is a parameter ,representing the amount of weight inspired.
● U expresses the n ant select the next step in all of the litter points.
● b' based on equation (7) gives the probability distribution to select a random variable.

$$p(a,b)=\begin{cases}\dfrac{\tau(a,b).\eta(a,b)^{\gamma}}{\sum_{s\in U}\tau(a,s).\eta(a,s)^{\gamma}} & b\in U\\ 0 \quad otherwise & (7)\end{cases}$$

Ants (= 1,2, ..., n) in the waste landfill sites selected point b of the transition probability.

⑤ Record the optimal solution ;

⑥ Update the amount of pheromone of the path to use the rules of quantum rotation gate;

⑦ If meet the output conditions (such as the maximum evolution generation =3000), then the optimal solution has been reached, otherwise set t = t +1 and return to③.

4. The test results

I order to verify the feasibility and validity of the method, the paper chooses CTSP16 and CTSP31 to simulate. In the experiment the number of the ant is equal to the number of the city. In this paper, the test result is the better.

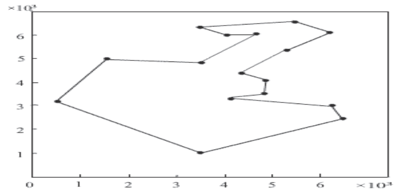

Figure 2 The route chart of the algorithm for solving CTSP16

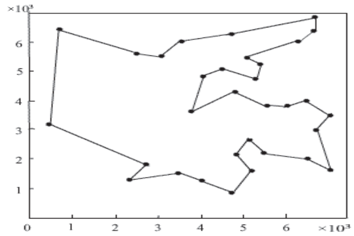

Figure 3 The route chart of the algorithm for solving CTSP31

The algorithm parameter settings are as follows: γ =2, t = 3000, q_0 = 0.8.

Table 1shows: This algorithm improves the speed greatly, convergence to an optimal solution , the number of iterations is decreased. Figure 2 and figure3 are the path graph of CTSP16 and CTSP31.

Table 1 The comparison of the basic ant colony algorithm and the algorithm of the paper to solve CTSP16 and CTSP31

TSP	ant colony algorithm	Algorithm of the paper	The average number of iterations	
			Algorithm of the paper	ant colony algorithm
CTSP16	74. 1087	73. 9988	29	338
CTSP31	132. 1203	131. 3411	51	612

5. Conclusions

Quantum algorithm is a new evolutionary algorithm, although the study is not long, the lack of solid theoretical foundation, but it has strong robustness and parallel computing, etc., it's very broad application prospects. the quantum algorithm and ant colony algorithm together, proposes an improved algorithm, greatly accelerated the speed of convergence of quantum algorithms.

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